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Immersion and Battlefield Visualization: Frame of Reference Effects on Navigation Tasks and Cognitive Tunneling

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ABSTRACT

We compared two types of electronic displays of battlefield information in order to determine how display frame of reference affects a military commander's situation awareness and diagnostic capabilities in a dynamic combat scenario.

US Military Academy officers viewed an unfolding ground battle scenario, presented as a sequence of computer-based slides, in one of two display view conditions. The first view condition was a 3-D exocentric (tethered) frame of reference (FOR) looking down at the terrain from 3000 meters above and 1200-1500 meters behind the commander's location, such that the commander's vehicle was always visible at approximately the same location on the screen (centered in the bottom third of the screen) for every scene. The second view condition was a combination display which consisted of an 3-D immersed egocentric view of the terrain from a viewpoint just above the command vehicle's location on the ground and a small 2-D contour map of the entire battle area embedded in the top center of the screen. Within each scene the officers were asked to verbally report any new enemy units or changes to existing units as well as to respond to a series of diagnostic questions about the particular scene and give confidence ratings of their selected answers.

Results showed that the tethered display produced worse performance on distance judgment tasks than the immersed display. Performance was equivalent across display conditions on questions involving direction judgments. The immersed display condition produced worse global hazard awareness than the tethered display condition, however confidence ratings for the global awareness tasks did not differ between display conditions. Additionally, immersed display condition subjects take longer to respond to, and show poorer performance on, questions requiring them to pan the environment than subjects in the tethered condition (which did not have a panning option). However, confidence ratings did not differ between display conditions on these questions, indicating that subjects may not have been adequately panning the environment to acquire information outside of the initial forward field of view. These two findings indicate that immersed condition subjects were unaware that they were missing enemy targets in the periphery, most likely because they were tunneling into the initial forward field of view and neglecting to pan the environment for additional information. Soldiers in the Immersed condition were also less sensitive to changes in enemy activity from one screen to the next. Implications of these results are discussed, regarding the potential deficiencies of highly egocentric or immersive displays for global situation awareness.

INTRODUCTION

Overview

      "Upon notification of a possible operation, the commander needs immediate knowledge of the projected area of operations and of the area of interest" (Department of the Army, 1997). Battlefield situation awareness consists of knowledge of the enemy and friendly forces as well as the terrain over which the operation is intended to play out. The ability of the commander to understand the terrain composing the area of interest is known as terrain visualization. Terrain visualization, which has always been a fundamental part of battlefield visualization (see TRADOC), is supported not only by the thoroughness of the data available but by how the data are displayed. In the past, commanders would walk the terrain personally or consult paper maps prior to a battle to get the lay of the land. Increasingly this terrain information is provided by technological means such as digitized terrain databases and computer-based displays. Banks and Wickens (1997) provide a thorough overview of the evolution of modern warfare aided by advanced information-gathering technologies, and emphasize the lack of relevant research in validating the types and formats of display technologies that are employed in a dynamic ground combat situation. Some effort has already been put forth to familiarize soldiers with training on terrain visualization using computer-based terrain displays. Barsam and Simutis (1984) studied the applications of computer graphic techniques to assist with terrain visualization. More recently, Banks, Wickens and Hah (1998) conducted a study which compared the effects of different display frames of reference of computer-generated terrain on performance of a set of military-related spatial judgment tasks, which will be discussed in more detail later.

      As the military begins to incorporate computer-generated displays on the battlefield to assist with command and control (C&C) decision-making, the display will become the primary source of information on which the commander must base his/her decisions. Thus display format becomes a fundamental issue in supporting various types of decision-making tasks. Display formats can vary by many different factors, including frame of reference, type and amount of information presented, and number of different viewpoints displayed simultaneously. Each of these factors can have a significant impact on the usefulness of a display, and it is necessary to determine how to manipulate these factors to provide the best possible display for every command and control task facing a commander. It has been found in studies of frames of reference issues that performance on a task is best when the specific frame of reference is compatible with that task (Wickens & Carswell, 1997; Wickens & Hollands, in press; Wickens & Prevett, 1995; Vincow & Wickens, 1998). In other words, a frame of reference which bests supports the mental processes required by a specific task will produce the best performance when compared to other frames of reference.

      There has been little research which specifically evaluates the effects of display types on situation awareness in decision-making processes in dynamic ground-based combat scenarios. Most of the currently available research on frames of reference and display viewpoints has been conducted in the aviation domain. Aviation-based studies have demonstrated that not all display viewpoints provide for equally good navigational control or situation awareness, and several robust trends, discussed in the next section, have emerged from this research. In order to determine how well these results generalize to a ground-based dynamic combat situation, we

must first understand the tasks faced by a commander on the battlefield and then assess which frames of reference best support those tasks. The current study is intended to evaluate the accuracy of the different mental representations produced by various display formats as well as clarify some of the cognitive biases induced by display frame of reference. In the following review we will discuss display frames of reference and their effects on spatial judgments, cognitive biases, and integration of information.

Frames of Reference

Frame of reference (FOR) refers to the viewpoint and dimensionality of the display, as illustrated in Figure 1 (Wickens & Hollands, in press).

There are three dimensions along which a display viewpoint can be defined: degree of egocentricity of viewpoint location, degree of vertical translation, and degree of lateral rotation (Wickens, 1999; Wickens & Hollands, in press). Egocentricity of location refers to the position of the viewpoint relative to the observer; the more egocentric the viewpoint, the closer the view is to what the observer would actually see in the environment. The most egocentric, or "immersed", FOR is a three-dimensional (3-D) view that corresponds most closely to the view a commander would have if he/she were to look out of the command vehicle, as represented in cell A in Figure 1. The information displayed in this type of FOR is relative to the observer's location as well as orientation. Only that information which lies in the direction that the observer is looking, the forward field of view (FFOV), is displayed. As the viewpoint becomes less egocentric, it is pulled away from the observer such that the view now displays the observer's location relative to the surrounding environment, as shown in the bottom four cells of the figure.

A more exocentric FOR can be either two- or three-dimensional, depending on the vertical translation of the viewpoint. When the viewpoint is vertically translated up at an angle between 1 and 89 degrees, some amount of the egocentric three-dimensional perspective is retained, as shown in the middle row of Figure 1. Also, when the viewpoint is removed from the observer's position, lateral rotation becomes a defining feature of the frame of reference. A 3-D exocentric viewpoint location can be "tethered" to the observer's location, always rotating to show the environment in front of the observer, as seen in cell B in Figure 1. This has the effect of making the viewpoint appear to follow the observer's motion through the space from a position above and behind the observer (also called a tethered view). A 3-D FOR with a fixed viewpoint is still more exocentric and shows the observer's location in the environment from some angle of perspective (viewpoint vertical rotation of 1 to 89 degrees), but the viewpoint is independent of the observer's motion and view of the environment remains fixed in azimuth and often in location, as shown in cell C of Figure 1 (Wickens, 1998; Wickens & Hollands, in press).

Lateral Rotation

		Rotating	Fixed
Vertical Rotation and Dimensionality	Immersed	**A**	
	Exocentric	Tethered Viewpoint **B**	**C**
	Plan-View	**D**	**E**

Figure 1. Features of egocentricity of a display. The three rows describe three different levels of vertical viewpoint location and rotation. The two columns describe two levels of lateral viewpoint rotation. The top three cells represent "3-D" or perspective displays, while the bottom two cells depict 2-D displays.

4

When the viewpoint is vertically rotated to 90 degrees, or directly overhead, elevation information is no longer available and the view becomes two-dimensional (2-D), represented by the bottom row of the figure. Here again the viewpoint can either rotate to follow the observer's movements through the environment or remain fixed and independent of the observer's motion. A 2-D exocentric FOR with a rotating viewpoint will display the environment with the heading up, rotating the environment around the observer such that the observer's motion always appears to be toward the top of the display, as shown in cell D in Figure 1. A 2-D exocentric FOR where the point of view is fixed directly overhead is most commonly displayed as a north-up contour map, shown in cell E in Figure 1 (Wickens, 1999; Wickens & Hollands, in press). Thus, in general, moving from the upper left cell to the lower right cell produces progressively more exocentrism of viewpoint.

Influence of FORs on Navigational Task Components

In the following sections we will discuss the effects of the two FOR dimensions which were experimentally manipulated in this study, vertical translation and egocentricity of viewpoint. A summary of the research conducted on "compromise" maps, or map displays composed of more than one view, is included as this was an important feature of one of the conditions in this study.

Effects of egocentricity of the viewpoint. In the field of aviation, a lot of work has been conducted on the effects of display FOR on performance of navigation tasks (Merwin, O'Brien, & Wickens, 1997; Olmos, Liang, & Wickens, 1997; Olmos, Wickens, & Chudy, 1997; Wickens & Prevett, 1995). Navigation tasks have generally been divided into two categories, those tasks which involve local guidance (travelling from point A to point B) and those which involve global awareness, usually of other air traffic and associated flight hazards in the areas around (i.e., including the sides, above, below, and behind) the observers (Olmos, Wickens, & Chudy, 1997; Wickens, 1995; Wickens & Carswell, 1997; Wickens & Prevett, 1995).

Wickens and Prevett (1995) proposed a model of navigation which suggests that the local guidance tasks are best supported by more egocentric views, while global awareness tasks are best supported by more exocentric views. The inverse is also expected to be true; egocentric views may hurt performance on global awareness tasks, and exocentric views may make local guidance tasks more difficult. Additionally, an expected cost of three-dimensional (immersed or tethered) displays is increased errors on location or distance judgments due to ambiguity along the line of sight, as compared to distance judgments made using a two-dimensional (plan-view) display. This model was supported by the results of their experiment, in which experienced pilots flew a landing simulation using various FOR displays which differed by degree of egocentricity. Pilots who used the most egocentric "immersed" viewpoint (cell A in Figure 1) produced the best navigation performance, whereas use of the more exocentric viewpoints (cells B and D) supported better global awareness (Wickens & Prevett, 1995).

Local guidance tasks in navigation involve understanding the environment in terms relative to the observer's current location orientation and trajectory (Wickens & Carswell, 1997).

The information most relevant to this type of task is located in the FFOV, which is the primary information displayed in an egocentric FOR. Studies have shown that more egocentric FORs do support local guidance tasks better than less egocentric displays (Barfield, Rosenburg, & Furness, 1995; Olmos, Wickens, & Chudy, 1997; Wickens & Hollands, in press; Wickens & Prevett, 1995). Exocentric views are less useful in navigation and guidance tasks due to the additional mental workload involved in transforming the image into one conducive to guidance (Wickens & Hollands, in press), as well as the reduced level of detail for the area just in front of one's own location.

On the other hand, more exocentric views (both 3-D and especially 2-D) provide a bigger picture view and thus better spatial awareness of areas to the side and behind the observer's location is supported. Components of navigational tasks, such as distance and direction estimates, are better supported by more exocentric displays (McCormick, Wickens, Banks, & Yeh, 1998). Additionally, when the objective of the observer is to scan the entire area for hazards, such as in a global hazard or situation awareness task, hazard information is immediately available in an exocentric display. A 3-D egocentric FOR display may limit scanning effectiveness in terms of added time taken to rotate the viewpoint, and the adequacy of hazard awareness may be degraded if subjects fall victim to the "keyhole effect," which causes them to anchor to the immediate forward field of view (FFOV) and forget to scan the periphery for additional hazard information (Aretz, 1991; Olmos, Wickens, & Chudy, 1997; Wickens & Prevett, 1995; Woods, 1984).

Three experiments by McCormick, Wickens, Banks, and Yeh (1998) revealed that travel time in a local guidance task was faster when the fully egocentric 3-D view was used than when either a 3-D mid-distance tethered view or full exocentric view was used. Performance on distance judgments of objects in the environment relative to the subject's position or a specified wall requiring relative distance judgments was best supported by more exocentric views. The authors suggest that this effect may be caused by the line of sight ambiguities inherence in more egocentric displays. Lastly, performance on recalling the number and locations of objects in the environment was best with the full exocentric view.

Barfield, Rosenburg, and Furness (1995) conducted a study in which subjects flew a simulated F-16 through a computer-generated airspace using either a "pilot's eye" (egocentric) or a "God's eye" (exocentric) HUD. Tasks included intercepting sequentially appearing targets (a local guidance task) and performing a post-flight spatial reconstruction of the airspace by positioning targets onto a 2-D plan-view of the entire flight scene (a global judgment task). As expected, subjects using the egocentric display had better target-interception performance, whereas subjects using the exocentric display were more accurate on the spatial reconstruction task.

Effects of vertical translation of the viewpoint. Van Breda conducted two studies which evaluated pilot performance on target acquisition tasks (a type of local guidance task) using two different exocentric viewpoints in a dynamic aviation simulation (Van Breda & Veltman, 1995). Target acquisition was faster and more accurate when the target information was presented more egocentrically (i.e., on a 3-D perspective tethered radar display with either a rotating or a fixed viewpoint) than when it was presented on a standard 2-D plan-view (fixed

viewpoint) radar screen. Van Breda points out that this results is in keeping with findings by Wickens, Liang, Prevett, and Olmos (1996) which indicate that time taken to scan the environment can be reduced by using a view that tunnels the observer into relevant areas of the environment.

A study that has looked at the effects of FORs on ground-based navigation tasks in a military context was conducted by Banks, Wickens, and Hah (1998). In this experiment, subjects were provided with three possible display viewpoints, a 2-D exocentric view, a 3-D exocentric perspective view, and a 3-D immersed view. The subjects were able to interact with this last display type by using a mouse to point and click to move to locations within the display as well as pan around a location. Results from this study indicate that distance judgment questions (a global judgment task) were best answered with the 2-D display. This finding was expected given that 2-D exocentric viewpoints tend to provide the least spatially distorted information, while more egocentric 3-D perspective FORs tend to distort spatial relationships by foreshortening distances between objects at different locations in the 3-D space (Banks & Wickens, 1997). Also, line-of-sight visibility questions were most accurately supported by the interactive immersive display (but included a time cost), which is reasonable since the immersive quality of this display type would reduce or eliminate any mental transformations needed in line-of-sight estimations performed using more exocentric FORs (Wickens, 1999).

Effects of "compromise" or combination maps (2 views vs. 1 view). Combination maps have been suggested as a method of compensating for the problems inherent to single FOR views discussed above. For example, a 2-D plan-view display provides no vertical information and thus could be coupled with an orthogonal view (which by itself would only supply vertical and no lateral information). This type of "coplanar" view has been employed in studies by Olmos et al. (1997), Haskell and Wickens (1993), Wickens, Liang, Prevett and Olmos (1996), and Wickens, Merwin and Lin (1994). Findings from these studies show that vertical information and vertical control when navigating is supported better (or at least equivalently) by coplanar views as compared to 3-D perspective views, because of the precision (lack of ambiguity) of such views.

Another example of a combination display is pairing a 3-D immersed view, which lacks information about the environment outside of the FFOV, with a more global exocentric view, such as a 2-D plan-view or a 3-D exocentric view. Vincow and Wickens (1998) showed that use of a combination map consisting of a 3-D immersed view and a small, inset 3-D exocentric view results in slower overall performance as well as attentional costs due to the need to integrate information across views that differ in dimensional scales.

Two experiments by Olmos, Wickens, and Chudy (1997) compared three types of display FORs (2-D exocentric coplanar view, 3-D exocentric tethered view, and a combination display consisting of a 3-D egocentric immersed view and a global view) in a dynamic, combat-related, aviation navigation and hazard detection simulation. The results of the first experiment suggest that the combination display, consisting of both a 3-D immersed egocentric view and a 3-D tethered exocentric view, produced a faster travel time when compared to performance using either a 3-D tethered view display or a 2-D coplanar display containing two orthogonal, exocentric views. However, in terms of hazard awareness, subjects using the combination display

did not perform as well as those using the tethered exocentric view. Results indicated that subjects heavily attended the immersed panel of the combined display to navigate and apparently did not adequately consult the more global exocentric view with which it was coupled, to alert them of global hazards. That is, their attention became "tunneled" on the forward view. Olmos et al. (1997) also found that there was a scanning cost for both combination views (split-screen and coplanar), and further that the split-screen display showed an additional cost due to information integration across the dimensional scale differences.

In general the research tends to show that the use of combination immersed and global displays may resolve some problems inherent to single view displays, but may introduce a new set of problems that arise from the need to integrate information from more than one view in order to form a complete picture. The benefits mentioned above include faster travel time, improved navigation, and more accurate elevation information. Some decrements inherent to combination views are a time cost due to the need to scan both displays as well as possible distortion or loss of display information due to size limitations for two (or more) views presented on one display. Finally, the combined displays may induce an inappropriate allocation of attention between displays often in favor of the more "compelling" immersed display, leading users to ignore potentially valuable information on one display or the other. Therefore combination displays should be used in situation when the potential benefits, such as faster navigation or accurate elevation or line-of-sight information, can outweigh the inherent costs, such as time costs and additional mental processing.

Given that different display frames of reference have been shown to have selective costs on different types of tasks, it is possible to infer that they might also selectively influence different types of cognitive biases in integrating information. We consider this hypothesis in the following section.

Cognitive Biases in Information Integration

The framework of this experiment will be an ongoing battle scenario. Commanders in such a situation are expected to continuously extract information from the environment and update their situation awareness in order to make the most accurate and effective decisions. They form initial hypotheses about the intentions or movements of enemy units in the area, which can either be confirmed, modified, or contradicted by incoming information. Decisions about courses of action are made based on the commanders' interpretation of enemy activity, which is dependent on their ability to correctly integrate incoming information (Cohen, Freeman, & Thompson, 1997). Two cognitive biases which have been found to have an impact on this type of decision-making process are the anchoring heuristic and confirmation bias (Perrin, Barnett, & Walrath, 1993; Taylor, Finnie, & Hoy, 1997; Tolcott, Marvin, & Bresnick, 1989; Woods, Johannesen, Cook, & Sarter, 1994; Mosier, Skitka, Heers, & Burdick, 1998; Wickens & Carswell, 1997; Wickens & Hollands, in press). When subjects weight information which supports a favored hypothesis more than evidence which contradicts it, it demonstrates that a kind of "mental anchor" has been attached to that hypothesis (Tversky & Kahneman, 1974; Wickens & Hollands, in press).

Anchoring heuristic. In an experiment by Tolcott, Marvin, and Bresnick (1989), the anchoring heuristic was defined as the operator's tendency to be relatively unresponsive to evidence against a favored hypothesis, in this case the initial report's prediction of enemy behavior. Using Army experts and strategists to assess a realistic battlefield simulation, Tolcott and his colleagues focussed on determining the effects of early judgments, in the form of preliminary field reports, on the "handling" of newly received information, which either confirmed, contradicted, or had no bearing on the initial report. The subjects in this experiment were to assess all of the incoming information (identical across conditions) and produce a final estimate of the enemy's behavior, as well as provide a level of confidence rating about their final decision. The results showed that even though all subjects got the same updates, which did not favor any of the three options, almost all subjects viewed the updating information as supporting their initial hypothesis, regardless of the actual accuracy of the initial hypothesis. This devotion to the initial judgment illustrates the anchoring heuristic: subjects tended to retain their initial hypothesis about the enemy's behavior by giving more credence to evidence that appeared to confirm this hypothesis and ignoring or devaluating contrary evidence.

Confirmation bias. The confirmation bias is similar to the anchoring heuristic in that the initial hypothesis is retained by the subjects, but involves actively seeking information that supports the favored hypothesis, rather than simply ignoring contradictory information (Wickens & Hollands, in press). A relevant example of the type of problems this particular bias may cause for decision-making tasks is that "tendencies to seek evidence that would confirm a hypothesis could lead to serious gaps in information collected, and result in overlooking evidence highly diagnostic of enemy activity" (Cohen, Freeman, & Thompson, 1997; Tolcott et al., 1989). In other words, officers who must make a decision regarding a course of action for their forces should base this decision on the most complete information on enemy activity. However, their ability to do this is subject to biases which cause them to rely too heavily on information which supports their initial interpretation of the enemy situation, which may or may not be accurate.

Perrin, Barnett, and Walrath (1993) conducted an experiment in which Naval tactical action officers were presented with a dynamic, realistic task simulation (including tasks such as monitoring enemy activity and identifying enemy aircraft) in order to evaluate whether the judgments made in a real-life setting would reflect decision biases such as the confirmation bias and the anchoring heuristic. Subjects were presented with a combination of visual (2-D radar display) and audio information, which represented near-continuous updates to existing information. Subjects in Perrin et al.'s study explained their chosen hypothesis by recalling and emphasizing information that supported it better than contradictory evidence. This evidence is similar to that found by Tolcott et al. (1989) and indicates that even when subjects are operating in a situation where they have been extensively trained to make objective and highly important decisions, they are still affected by the same kinds of biases evident in laboratory studies.

Display Influences on Cognitive Biases and Information Integration

The same cognitive biases which cause subjects to anchor, or tunnel, to one hypothesis or set of information can possibly be enhanced or diminished when the visual display of information is manipulated. To illustrate, research on frame of reference effects described above suggests that subjects' poor performance on global hazard awareness tasks when using egocentric

displays is due to a tendency to tunnel into the FFOV displayed in a 3-D immersed view and either disregard information outside of the currently displayed FFOV or forget to look for it altogether. This has been demonstrated in numerous studies where global hazard awareness suffers when the observer relies on a 3-D immersed view display (e.g., Taylor, Finnie & Hoy, 1997; Yeh, Wickens & Seagull, 1998; Olmos, Wickens & Chudy, 1997). Olmos et al. (1997) showed that the mere presence of an immersed viewpoint led subjects to tunnel in on it (the immersed viewpoint) and ignore more global information directly available on another map display.

An example of display-induced tunneling is demonstrated in a study by Yeh, Wickens and Seagull (in press). Subjects were presented with a 3-D immersed display of mountainous terrain and were asked to detect targets in the environment. Targets varied by whether they were cued or not, and also whether they were expected or not. The most important target (in this example, a nuclear device) was uncued, unexpected, presented rarely, and always presented in a scene with an expected target. When the expected target was cued and a nuclear device was present, subjects tended to focus (or tunnel in) on the cue and missed detecting the nuclear device altogether. In other words, subjects were anchored by the saliency of the cue, which they knew reliably indicated an object in the area, and thus were drawn immediately into looking for the cued object (confirming the hypothesis that there is an object in the area) at the expense of the more important task of monitoring for the uncued nuclear device. An additional factor varied in the experiment was display FOR. Yeh and Wickens (1999) also found that the tunneling effect was enhanced when information was presented on an immersed HMD, relative to an exocentric hand-held display.

Dynamic or time-pressured presentation of information, such as in an air or ground-based battle simulation, is predicted to have the effect of causing subjects to show cognitive biases in their judgments or decisions because of the reduced opportunity to proactively seek out more information (Pascual & Henderson, 1997). Display-induced tunneling has been demonstrated in dynamic combat scenarios in the military aviation domain (Taylor, Finnie & Hoy, 1997).

Current Study

Much of the existing research on display frame of reference effects has been performed in the aviation domain, using realistic flight scenarios to study these effects on navigation tasks (e.g., Olmos et al., 1997; Wickens et al., 1994). The terrain or ground-based studies which have investigated display FOR effects presented subjects (mostly military officers) with visual displays of terrain information but the subjects were asked to perform general information-gathering or visual search tasks on a series of unrelated scenes (e.g., Banks et al., 1998; Yeh et al., 1998, in press). On the other hand, studies that have been done using an on-going battle scenario, e.g., Tolcott et al. (1989), Perrin et al. (1993), have been mostly paper-based experiments which focused on evaluating decision-making biases and expertise in military officers. In sum, there don't seem to be any studies which focus on evaluating different types of displays for supporting decision-making or navigation tasks based on continuously updated information from an on-going ground-based military scenario.

Our goal here was to combine these two lines of research, frames of reference effects and situation updating in a combat context, and create an experiment which uses a realistic on-going ground battle scenario to evaluate the effects that different display frames of reference have on situation awareness, navigational task components, and decision-making tasks. Based on the above findings and suggestions from previous research, we decided to compare two displays which we inferred would best support the majority of these tasks. One of the display conditions used a tethered 3-D exocentric display (cell B in Figure 1), and the other used a combination display containing an immersed, interactive 3-D egocentric view (cell A) and a small 2-D north-up plan-view contour map (cell E) with a wedge that indicates the current heading/field of view, similar to the wedge developed by Aretz (1991). This second condition which we label the "immersed" view represents a "compromise" display, such as has been suggested in Wickens, Gordon and Liu (1998) and Wickens and Hollands (in press), and employed in studies by Vincow and Wickens (1998) and Olmos et al. (1997). The combination display in this experiment was chosen because the benefits from use of both views outweigh the potential costs discussed above. Specifically, the immersed view is expected to provide the subjects with readily accessible information about the immediate environment, while the 2-D inset map provides information about relevant objects (such as enemy units) in the environment that may be hidden by terrain in the immersed view. We also assumed that the 2D inset map hosted more permanent "confirmed" information regarding enemy units, but not unconfirmed reports, only visible on the tethered view. Although there was a difference in scale between the two views, scanning costs were mitigated by the fact that the 2-D inset map provided only limited information and thus did not overwhelm the subject with integration tasks. In addition, the use of the wedge was designed to create visual momentum and to ease the cognitive burden of integrating the two viewpoints (Woods, 1984).

The experiment included computer-based questions specifically aimed to evaluate performance on navigation-related tasks such as judging the distance and direction to enemy objects relative to the observer's location. Additionally, global hazard awareness was measured by the accuracy of the counts of enemy objects visible in the environment. Performance on these different judgment tasks could then be compared between display conditions to determine which display best supports each type of task, similar to the analyses run by Banks et al. (1998).

Also, we investigated differences in performance between display types based on the expected panning activity in the Immersed condition. Since subjects in the Tethered condition did not have the option of panning the environment, each Tethered condition scene contained all of the information necessary to answer all questions correctly. However, for the Immersed condition, some of the information was not presented in the initial FFOV (e.g., enemy units located behind or to the side of the subject's location and initial orientation), therefore the subjects were expected to utilize the panning option to rotate the viewpoint and scan the environment to obtain all of the information. Some questions did not require any panning (e.g., initial heading questions), some questions may prompt the subjects to pan to confirm that they are not missing any information (e.g., questions regarding number of unconfirmed enemy units, which did not appear in the 2-D plan-view map, when all of the unconfirmed units happened to be visible in the initial FFOV), and some questions absolutely required panning activity to gather all of the needed information (e.g., questions regarding number of unconfirmed enemy units, given that not all of the units were visible in the initial FFOV). We compared levels of

performance on each of these panning categories by viewing condition to determine how well Immersed condition subjects used the panning option to acquire all relevant information.

Based on the predictions made by the model of navigation proposed by Wickens and Prevett (1995), as well as other research findings (e.g., Olmos, Wickens & Chudy, 1997), we hypothesized that the more exocentric display would best support the subjects' distance and direction judgments to enemy units relative to the observer's position in the environment. Additionally, based on the findings of Yeh, Wickens and Seagull (1998, in press), Yeh and Wickens (1999), and Olmos, Wickens and Chudy (1997), we hypothesized that subjects would tend to fixate or tunnel into the FFOV in the more egocentric (Immersed condition) display because of its primacy and salience, thus producing worse performance on global awareness tasks than subjects in the Tethered condition. This cognitive tunneling effect would be revealed in the decrement to performance by subjects in the Immersed condition as panning becomes more required for gathering the information necessary to correctly answer the questions. An evaluation of the responses made by the subjects within each of the categories of expected panning behavior may reveal if the subjects appeared to rely more extensively on information available solely in the initial FFOV viewpoint even when panning was required, and thus suggest that subjects were cognitively tunneled into the initial FFOV. Subjects in the Tethered condition should not have been affected by this kind of cognitive tunneling effect because of the "bigger picture" view afforded by a 3-D exocentric FOR, and the fact that all information must be provided in the one static view seen by those subjects. In addition, we expected to find that the Tethered condition subjects would detect and annunciate more changes to enemy units than subjects in the Immersed condition, given that cognitively tunneling into the limited initial FFOV would restrict Immersed subjects' exposure to changes that occurred outside the FFOV.

In accordance with the expectation that the Tethered condition subjects would achieve greater global hazard awareness during the experiment, we expected to find that Tethered subjects would perform better on the post-experimental map choice task. The results of studies which included similar spatial reconstruction tasks such as McCormick, Wickens, Banks, and Yeh (1998) and Barfield, Rosenburg, and Furness (1995) support the hypothesis that more exocentric displays produce better performance on post-experimental object recall and scene reconstruction.

METHODS

Participants

62 officers (59 males, 3 females) from the United States Military Academy at West Point voluntarily participated in this study. These officers included 35 captains, 13 majors, 12 lieutenant colonels, and 1 colonel from various branches within the Army. The mean years of active duty service was 12.63, and ranged from 8 to 25 years. Participants were run in two different sessions; 32 officers in the pilot session and 30 officers in the experimental session (30 total). Within each session, half of the participants were randomly assigned to the immersed display condition, and half were assigned to the tethered display condition.

Apparatus

The experiment was displayed on a Silicon Graphics 20 inch color monitor and run using BattleView software on a Silicon Graphics Octane workstation. The terrain information was produced from geological surveys of the National Training Center in Ft. Irwin, California. A terrain image of the area was obtained from a true-color satellite photo of the area.

Participants used the mouse to select answers and confidence ratings for both conditions. Participants in the immersed condition were also able to manipulate the display viewpoint by "panning" to the left or right. The panning feature was slaved to the right and left mouse buttons such that if the subject placed the cursor over any part of the display and clicked the left button, the view would pan to the left. Single clicks of the mouse button resulted in discrete changes to the viewpoint of 10 degrees to each click. Holding the button down resulted in a continuous sweep of the area, including the entire 360 degree rotation, which would be completed in 8 seconds.

Stimuli

The two display view conditions evaluated in this study offer three distinct viewpoints that contain different frame of reference features. All three displays showed a relatively flat-bottomed valley surrounded by mountainous terrain. Figure 2 provides an overview of the entire battle area, looking to the west. The path through the terrain was depicted in a series of 25 successive scenes. Each scene change represented an advance of about 3-4 km along the path of travel, representing an overlap of about 75% from one scene to the next. Since the path curved from north to west to northwest over the course of the 25 scenes, the degree of overlap between successive scenes varied but, generally speaking, enough of the terrain and other cues (such as enemy symbols) remained constant between successive scenes that a degree of continuity was maintained.

Tethered condition. The Tethered display condition consists of a 3-D exocentric view, where the viewpoint was always located approximately 3000 meters above the ground and 1200-1500 meters behind the ego reference point, a realistic tank icon. Figure 3 depicts the first scene presented to the subjects in the Tethered condition. The viewpoint was always oriented along the movement of the unit into battle. This positioning of the viewpoint produced the effect that the command tank icon was always visible at approximately the same location on the screen (centered in the bottom third of the screen) for each successive scene, and the areas behind, to the sides, and in front of the tank could be seen. This "footprint" area seen in each tethered display scene contained all of the information necessary to respond correctly to the question(s) for that scene, but no more information than could be seen in the immersed display for the corresponding scene. The subject could not interact with the display, but instead observed the scene passively. Roads were shown as white lines, in contrast to the mostly green and brown terrain.
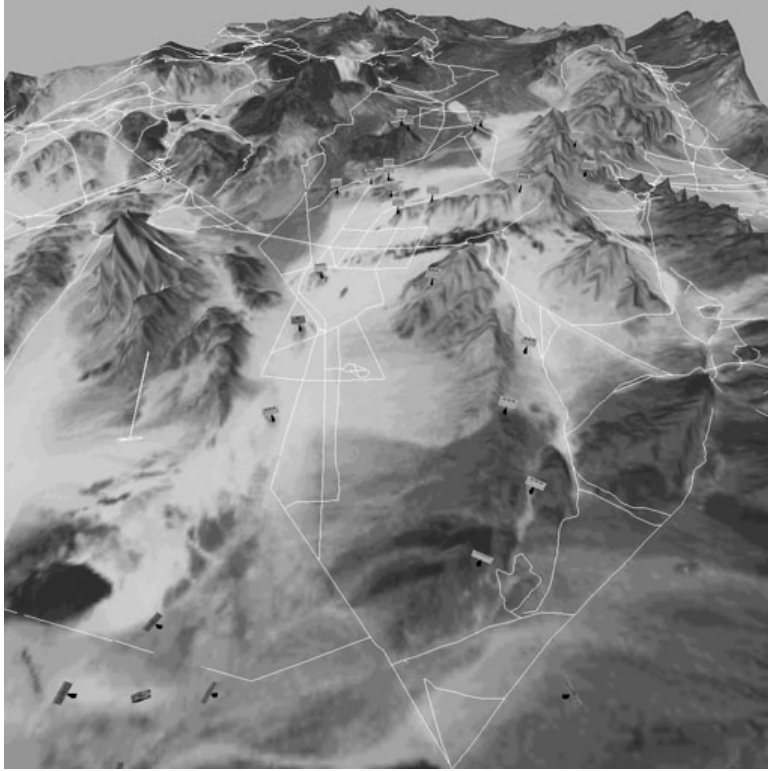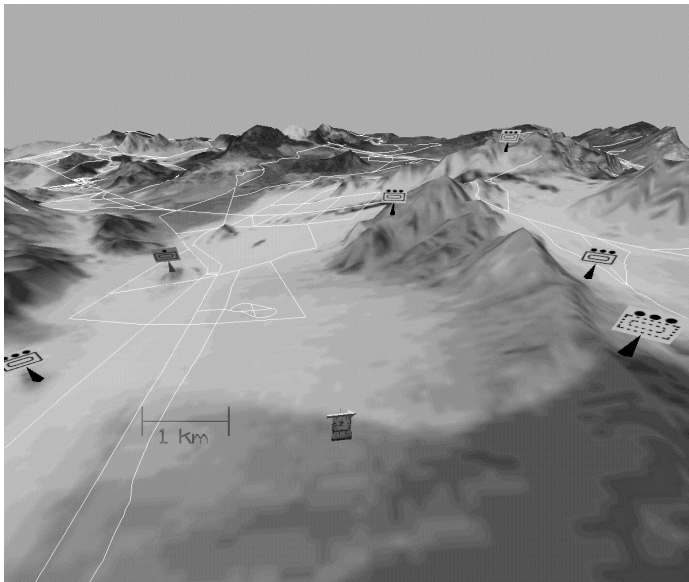
Figure 2.

Figure 3. Exocentric ("tethered") 3D display.

Immersed condition. The immersed display condition presented two viewpoints simultaneously. Figure 4 shows the first view presented to subjects in the Immersed condition. A 3-D egocentric view could depict, with some panning interaction, the same terrain as the tethered condition, but from the perspective that the commander would have at eye level (2 meters above the ground) from his/her location. The view encompassed a 90 degree geometric field of view at any one time. The default view at the start of every scene showed the terrain directly ahead according to the battalion's trajectory (i.e., oriented along the same axis as the tethered view for that same scene). Subjects were able to rotate the viewpoint by panning, as described above, to cover the entire 360 degree range. Refer to Appendix A, slides 1-5 to compare one scene (Scene 8) viewed in the Tethered perspective (slide 1) to four different rotations of the viewpoint (W, S, E, N, respectively) in the Immersed condition (slides 2-5; slide 5 represents the initial FFOV).
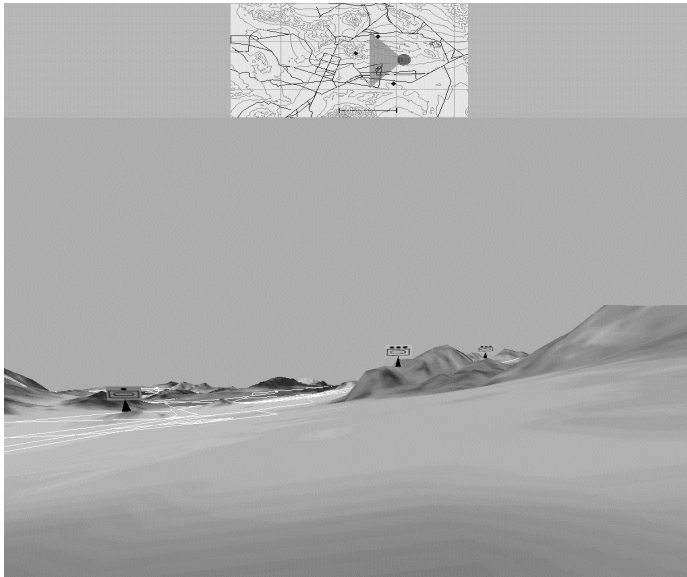

Figure 4. Immersed 3D display. The small map at the top is a plan view, with the observer's location and forward view depicted by the triangle.

Embedded in this 3-D immersed view, a small (2.5 x 3 inch) 2-D exocentric contour map located at the top center of the screen displayed the entire area of interest. The inset map was located in such a way that it did not obscure any relevant information from the immersed view (i.e., only part of the sky was covered by the inset map). Subjects in this condition could track their battalion's progress in the 2-D inset map and observe the terrain from the tank's perspective in the immersed view map. This 2-D inset map was white with superimposed red contour lines and black lines which represented the roads in the environment. The commander's current location on the 2-D inset map was depicted by a small yellow circle. The area currently visible in the 3-D immersed view was represented on the 2-D inset map by a blue "wedge," (Aretz, 1991) which acted like a spotlight to illustrate the extent of the immersed view, which opened up in the direction the commander was facing and illustrated the extent of the view seen in the 3-D immersed view. Note that the wedge is rotated in each of the Appendix A slides 2-5 to show the new direction and field of view displayed in the 3-D immersed view below the 2-D inset map. Neither the 2-D inset map nor the 3-D immersed view alone contained all of the necessary

information to answer the questions correctly, but the combined information was always sufficient. To illustrate, the 2-D inset map may show a confirmed enemy unit (described below), which is not visible in the 3-D immersed view because it is blocked from view by a mountain range or is "behind" the current orientation and can only be seen after panning. Alternatively, the 3-D immersed view may show several unconfirmed enemy units which don't appear on the 2-D inset map because this map only depicts confirmed intelligence information. For every scene, both views are needed to get the most complete information.

Enemy symbols. In both 3-D perspective views (immersed and tethered), enemy units were represented by red signposts marked with standard military symbols for size (e.g., company) and type (e.g., armored division) which were embedded within the terrain such that terrain features could partially or entirely obscure the signpost (source: FM 101-5-1, *Operational Terms and Symbols*). Examples of these symbols are present in Figures 2, 3, and 4, and slides 1-10 in Appendix A. Subjects were informed that unconfirmed units were marked with dashed line symbols, while confirmed units were marked with solid lines. Unconfirmed units were considered to be templated, that is, based on unreliable information, and either became confirmed in a subsequent scene or disappeared altogether if the information was found to be incorrect. Three unconfirmed units became confirmed during the course of the scenes' updating, and two disappeared altogether, although in one case a new confirmed enemy appeared in one scene near the location of an unconfirmed enemy which was no longer present in that scene, and thus could be interpreted as the same enemy unit, but repositioned and confirmed. Confirmed enemy units were based on reliable information. Friendly units were represented by blue signposts marked in similar fashion to enemy units. Both friendly and enemy (confirmed and unconfirmed) symbols were present in the Tethered condition and in the immersed view of the Immersed condition. However, in the 2-D inset map in the Immersed condition, only *confirmed* enemy targets were visible, depicted as small red diamonds; no friendly or unconfirmed enemy units were shown.

For the tethered condition, the maximum number of enemy shown at any point in the battle was five. Up to eight enemy units could be seen in the immersed condition's immersed view (up to 14 at a time on the 2-D inset map), but this included some enemy units that were over 15 km behind the battalion's current position. The subjects were informed that these far distant units were not considered relevant to the current situation and could be excluded from verbal reports.

Battle updates and questions were presented in boxes in a column to the right of the terrain display and did not obscure any part of the display. Answer and confidence rating choices were always displayed as buttons within the boxes, which the subject could select with the mouse.

The Battle Scenario

The first section of the battle scenario was intended to let subjects familiarize themselves with the display and the type of information to be encountered. The battalion was initially positioned facing due north, and traveled north for the first 4 scenes. Only friendly units (which subjects were told to ignore in their verbal reports) were visible in the first scene; enemy units began to appear in Scene 2. After Scene 4, the battalion began a slow turn and traveled west for

the next 9 scenes. Enemy activity in this section was limited to appearances of new enemy units and changes to status (from unconfirmed to confirmed).

The change between Scenes 13 and 14 marked the second section of the battle; there were no enemy units visible in Scene 13, but two companies appeared in the FFOV in Scene 14. While the battalion progressed northward toward a mountain pass, additional enemy companies appeared and all of the enemy units were eventually destroyed by the battalion over the course of the next four scenes. Enemy activity included appearances of new companies and destruction of existing companies, which was also explicitly announced to the subjects through a series of written updates which appeared automatically with each successive scene.

The change between Scenes 18 and 19 represented the last segment of the battle. In Scene 18 the battalion was heading through the mountain pass and no enemy units were visible, and in Scene 19 five enemy companies appeared in the forward field of view, in a semicircle surrounding Objective Illinois, the battalion's destination as described in the instructions. Enemy activity in this last section included partial destruction of enemy companies (leaving one or two platoons that appeared in successive scenes, and then were destroyed themselves). Partial and complete destruction of enemy companies was also explicitly announced to subjects through written updates.

During the experiment, subjects were to verbally announce any new enemy units, or changes to existing units, that they saw. These verbalizations were tape recorded for later analysis. Between scenes, but never within a single scene, units could change location, size, and status (from unconfirmed to confirmed). Except for the scene change between Scenes 18 and 19 described above, the degree of change of enemy units was limited to a maximum of two changes between successive scenes (i.e., one unit might appear and one other might change from unconfirmed to confirmed), but in general only one change occurred between scenes. Subjects were also asked computer-based questions, which required judgments about distances to, directions to, and count of enemy units in the environment.

Tasks

During each session, the participants were randomly assigned to one of the two display conditions (Immersed or Tethered), and each group was given instructions specific to that condition. After the participants had read and signed the consent form, they were asked to follow along with the instructions as they were read aloud by the experimenter (see Appendix B, Instructions). There were three tasks involved in this experiment; two tasks were performed simultaneously during the scene presentation, and the third was performed after all of the scenes had been observed.

The subjects were told that, once the scenes began, they should first verbally announce any enemy reports for each scene, remarking especially on new enemy locations and changes to the status (e.g., unconfirmed to confirmed) of existing enemy units. Enemy reports were requested to include distance and direction judgments and size and type information of each enemy unit (if that could be determined), but could also include possible intent or perceived movement of the enemy, and loss of sighting or destruction of an enemy unit.

After the verbal report was made, the subjects' second task was to respond to the computer-based questions that appeared along the right-hand side of the display. These questions consisted mainly of the navigational task components of distance and direction judgments and a global hazard awareness task requiring tallies of enemy units (for confirmed, unconfirmed, or both). Also, in the Immersed condition, some questions absolutely required the subjects to pan the environment (Required Panning), some questions did not require panning but subjects should pan to confirm their information (Desired Panning), and the remaining questions did not require any panning at all since all relevant information was included in the FFOV (Forward). Each scene contained one, two, or three questions. Examples of commonly asked questions are "How many unconfirmed enemy units are currently visible?" and "What direction is the closest enemy unit from your battalion?" Prior to beginning the experiment, participants were informed that they would have a maximum of 3 minutes to complete all of the questions from each scene. Once an answer was selected, the answer remained highlighted and a confidence rating box appeared below the question box. Subjects were to provide a confidence rating to the selected answer from "Confident," "Moderately Confident," and "Not At All Confident." After all of the questions were answered and confidence ratings were entered from one scene, the next scene and the corresponding first question would automatically appear. Subjects who did not make a verbal report for a scene before responding to all questions in that scene were not able to remark on that scene as it automatically was replaced by the successive scene. If subjects did not make visual reports in two consecutive scenes, they were prompted by the experimenter to comment on the next scene.

After the 25 scenes were viewed, subjects were asked to select a map from a choice of four that most closely represented the entire battlefield, including all friendly and enemy positions. Each subject was presented with two qualitatively different sets of four maps, one that depicted the battle scene on a flat two-dimensional grid map and one that presented the battle area in a perspective three-dimensional map. The order of presentation of the maps was balanced across the two viewing conditions.

After completing all three tasks, subjects were given a questionnaire which asked them to rate the display according to how useful it would be in a real combat scenario and to describe any benefits or problems they observed with the display (see Appendix C, Questionnaire). Participants were also asked to provide information about rank, branch of service, and years of active duty. After the questionnaire and final consent form were completed, the experimenter thanked the participants and debriefed them on the purpose of the experiment.

RESULTS

The data were analyzed using the Statistical Analysis Software (SAS) package. After eliminating eight single-response items (status updates), the data from the remaining 37 questions were first filtered according to an overall response criteria; if the results from both display conditions showed less than 50% of subjects selecting the correct answer, the question was dropped. Five questions failed this criteria. Also, one question which, due to screen artifacts, resulted in different but correct answers for each display was eliminated. Unless otherwise noted, data analyzed are from the experimental session.

Panning strategy categories. Data from the remaining 31 questions were sorted into 3 question categories, based on what panning strategy had to be adopted in the immersed condition to produce the correct answer. The 3 categories were:

1) Forward: all of the information needed to correctly answer the question was provided in the initial forward field of view (FFOV), therefore the question did not require a survey of the environment by panning.

Sample question "What direction are you currently heading?"

2) Pan-Desired: by coincidence all of the information needed to correctly answer the question was provided in the FFOV, or was included in the 2-D inset map, but the subjects should have panned the environment to confirm their answer.

Sample question "What confirmed enemy outpost is positioned best to call indirect fire on your battalion?" (Note: Enemy can call indirect fire when they are at higher elevation than the target. Elevation information can be ascertained by the contours in the 2-D inset map, but using the immersed view can make differences in elevation more salient than the 2-D contour lines.)

3) Pan-Required: subjects should not have been able to answer the question correctly without panning the environment to gather all the necessary information.

Sample question "How many enemy units (confirmed and unconfirmed) are visible?" (Note: Confirmed enemy can be seen in the 2-D inset map, but unconfirmed units are only visible in the immersed view.)

The Forward category contained 13 questions, and Pan-Desired and Pan-Required each had 9 questions. Percentage of correct scores for each category were determined for each subject. A 2-way ANOVA was performed on these correct percentages for question category by display condition as shown in Figure 5.

There was a significant main effect for question category [$F(2,87)=8.93$, $p<0.004$]; overall, performance decreased as expected panning behavior increased. Display condition also produced a main effect [$F(1,88)=7.03$, $p<0.002$], generally favoring the tethered display.

The interaction between question category and display condition [$F(5,94)=15.09$, $p<0.0001$] is evident in the changes in performance from Forward and Pan-Desired to Pan-Required questions. This interaction revealed that the advantage for the Tethered condition display emerged for Pan-Desired questions ($t_{28}=1.79$, $p<0.084$) and was amplified as more panning was required. For the Pan-Required questions the Tethered condition produced significantly better performance ($t_{28}=3.69$, $p<0.001$).

Further investigation into the effects of question category was conducted as a 2-way ANOVA using response times, averaged by subject, for each panning category by display condition as shown in Figure 6.
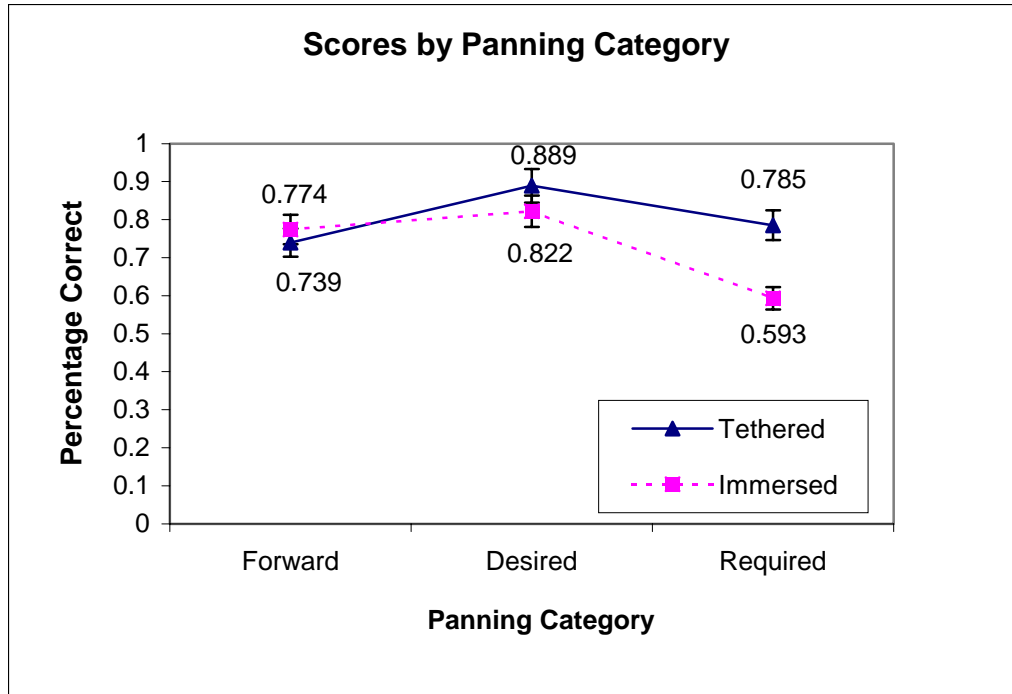
Figure 5. Percentage of correct scores for each panning category, by display condition with 95% error bars.
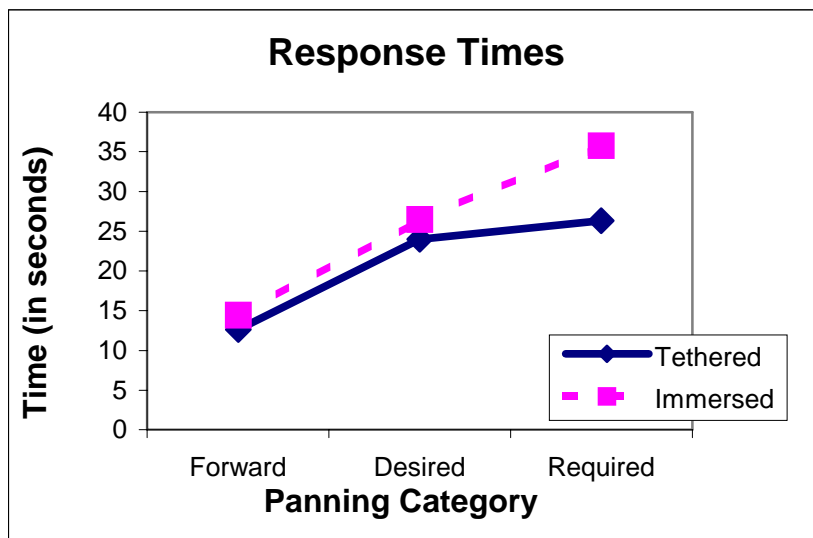

Figure 6. Average response time for each panning category by display condition, with 95% error bars.

The results indicate that there is a significant main effect of panning category [$F_{(2,87)}=39.69$, $p<0.0001$]; response times for both display conditions increase as questions require increased panning behavior. The main effect of display condition [$F_{(1,88)}=7.87$, $p<0.006$] shows that the Tethered condition subjects performed faster than Immersed subjects at each panning category. There is a trend toward an interaction between panning category and display condition [$F_{(5,84)}=2.24$, $p<0.112$], but it is only evident in the difference in display conditions on the Pan-Required questions. Tethered condition subjects showed essentially the same significant increase in response times between Forward and Pan-Desired questions as the Immersed condition subjects, despite not having a panning option ($t_{28}=5.46$, $p<0.001$). This equivalence suggests that the questions become progressively more complex from Forward to Pan-Desired, either in terms of their search demands or number of alternatives (i.e., for reasons unrelated to Immersed condition panning behavior). However, the difference in RT for Tethered condition subjects between Pan-Desired and Pan-Required questions is not significant ($t_{28}=0.68$, $p<0.50$), indicating that Pan-Required questions are no more complex than Pan-Desired questions. Thus, the significant 10 second increase ($t_{28} = 2.87$, $p<0.008$) in RT in the immersed condition between Pan-Desired and Pan-Required must be due to other sources. This difference between display conditions for Pan-Required questions is just over 9 seconds, or roughly the equivalent time for a continuous 360 degree pan of the environment (a complete and continuous pan takes only 8 seconds). Thus for Immersed condition subjects, the response times for both of the panning categories can be partially accounted for by the added time it would take to pan the environment.

This pattern of data suggests that Immersed condition subjects may not have adequately panned the environment in Pan-Desired questions, since the increase in response times between Forward and Pan-Desired questions was no larger in the Immersed condition (12.07 seconds) than in the Tethered condition (11.37 seconds). When combined with the above decrement in accuracy for the Immersed condition subjects (Figure 5), these data indicate that those subjects did not adequately pan when panning was desired. The further decrease in relative accuracy on the Pan-Required questions suggests that although subjects may be taking some advantage of the panning capability they are failing to fully capture the relevant information on the display.

Confidence ratings – panning condition. A 2-way ANOVA was performed on confidence rating data for each of the three panning categories by display condition as shown in Figure 7. Confidence was rated as follows: 3 = "Confident," 2 = "Moderately confident," and 1 = "Not at all confident."
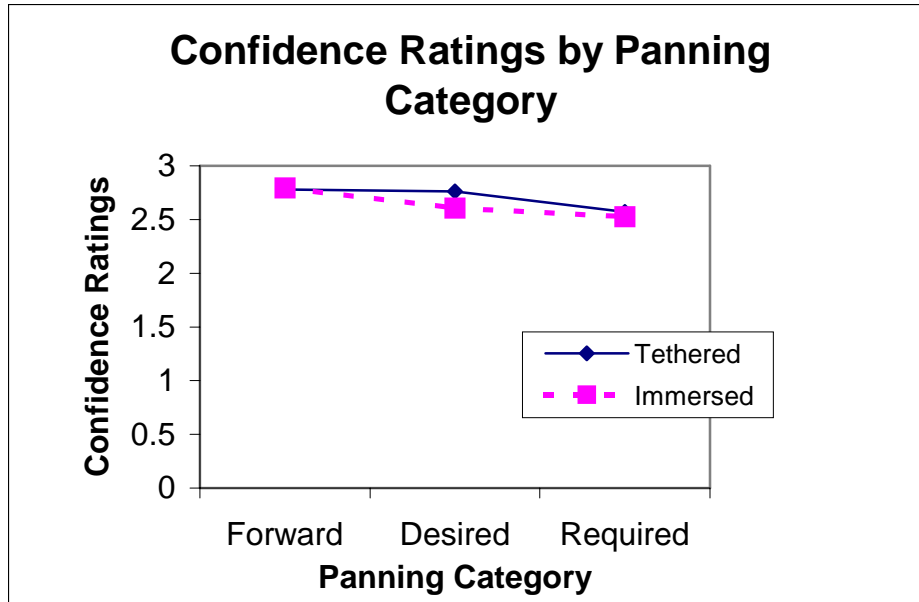
Figure 7. Confidence ratings for each panning category, by display condition, with 95% error bars.

Results revealed only one significant main effect, that of panning category [$F(2,87)=5.57$, $p<0.0002$]; as the questions required more panning behavior, confidence ratings decreased. Although Immersed condition subjects showed significantly worse performance and slower response times for Pan-Required questions than did the Tethered condition subjects (Figures 5 and 6), there was no significant difference between the two display conditions' confidence ratings for this category ($t_{28}=0.54$, $p<0.59$). This equivalence indicates that subjects are highly confident about their answer selection to Pan-Required questions despite the fact that the actual results show their performance to be less accurate. High confidence and less accurate performance on Pan-Required questions suggest that the Immersed condition subjects are tunneling into the initial FFOV and neglecting to adequately pan the environment for additional information which may be (and in the case of Pan-Required questions, is) located outside the initial FFOV.

Spatial judgment and situation awareness categories. The questions were next recategorized by content into three types in a trichotomy that more closely follows that used by Banks, Wickens, and Hah (1998): direction judgments (16 questions), distance judgments (3 questions), and judgments on number of enemy visible (5 questions). The remaining 7 questions could not be combined to form any other categories and thus were excluded from this analysis. A similar ANOVA to that performed on the panning categories was again carried out.

Subjects in both display conditions performed best on direction judgments (around 88% correct) as seen in Figure 8. The interaction between display conditions and question types [$F(5,84)=9.86$, $p<0.0001$] becomes evident in the distance judgment questions and questions about the number of enemy units visible.
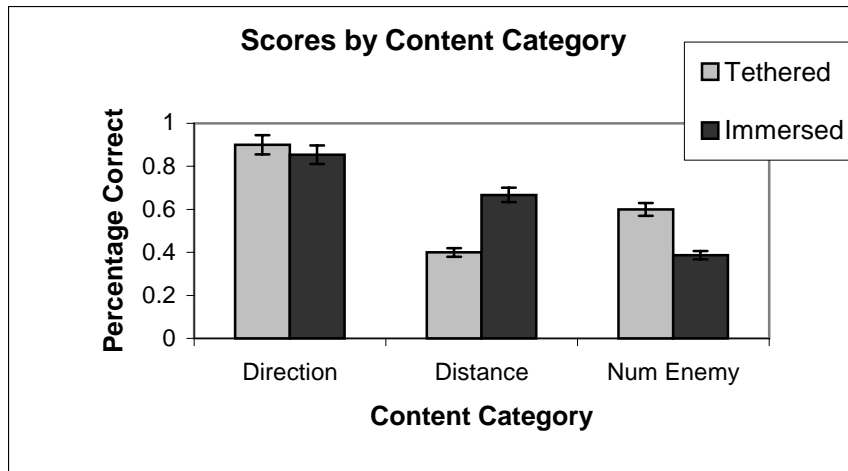
Figure 8. Percentage of correct scores for each content category, by display condition, with 95% error bars.

Subjects in the tethered condition performed *worse* than subjects in the immersed condition on questions about distance judgments ($t_{28} = 2.26$, p< 0.032). It was expected that the tethered condition subjects would have a more difficult time assessing distance given the spatial distortion of that particular view; subjects in the immersed view were aided by the undistorted scaled 2-D inset map. However, subjects in the tethered condition performed *better* than the immersed condition subjects on questions about number of enemy visible ($t_{28} = 3.76$, p<0.0008). This was expected given that all of the information about the enemy was visible in the tethered condition's static view in order for the subject to be able to answer the question correctly (and thus was immediately present), while in the immersed condition some of these questions required the subjects to survey (i.e., pan) the environment to get all of the information about the enemy (which they may or may not have done effectively, as demonstrated by the poor accuracy of those subjects on questions requiring panning as seen in Figure 5).

Confidence ratings – spatial judgment categories. Confidence ratings were compared by display condition for each content category as seen in Figure 9.

Despite the fact that performance on distance judgment questions was significantly worse in the Tethered condition than the Immersed condition, there was no significant difference between the confidence ratings provided by each display condition (t_{28}=1.15, p<0.26). Additionally, there was no significant difference between the display conditions' confidence ratings on number of enemy visible questions (t_{28}=0.36, p<0.75) even though performance here was markedly worse in the Immersed condition than in the Tethered condition. The high confidence and less accurate performance on this global hazard awareness task also provides evidence that subjects in the Immersed condition were tunneling into the initial FFOV and forgetting to pan the environment for information that may fall outside the FFOV.
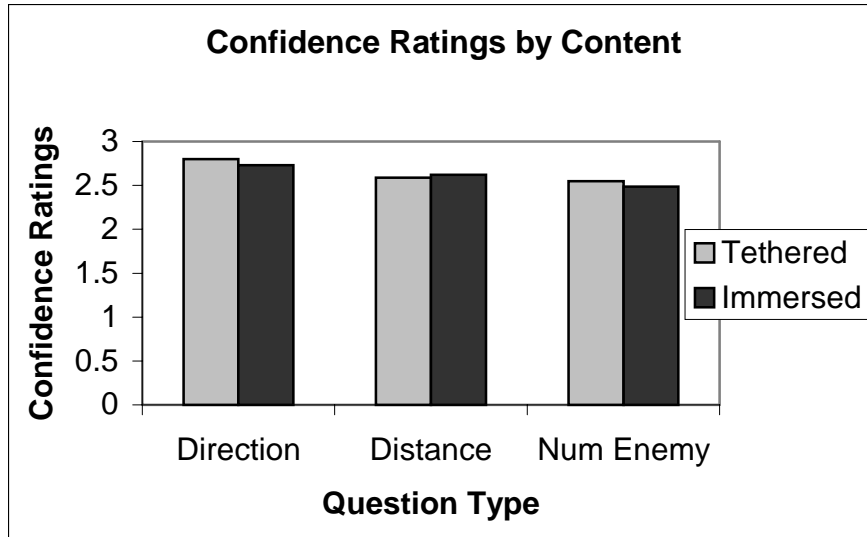
Confidence Ratings by Content

Figure 9. Confidence ratings for each content category by display condition, with 95% error bars.

Verbal protocol data. A significantly greater number of changes were detected and spontaneously reported by subjects in the Tethered condition, compared to performance in the Immersed condition (t_{28} = 7.10, p<0.0001). Out of 45 total status changes per condition (3 changes each for 15 subjects), 13 instances of unconfirmed enemy units becoming confirmed were reported by Tethered condition subjects, while only one change was reported by any of the Immersed condition subjects.

In addition to the global analysis by question category described above, some insight into the strengths and weaknesses of the two viewpoints can be gained by a more focal analysis of specific questions on two specific scenarios, as described as follows.

Map integration analysis (Scene 8). Performance decrements for Immersed subjects as compared to Tethered subjects on count of enemy units may be due to a problem in the integration of information between the two views in the Immersed condition since soldiers had to consult the 2-D inset map for some confirmed enemy units (that were obscured by terrain in the forward view) and only the immersed view for unconfirmed enemy units (none of which were hidden by terrain). Scene 8 provides a clear example of a situation where the two display conditions presented the same information about the number of enemy units visible (refer to Appendix A slides 1-5). However, difficulty in integrating the information in the Immersed condition led to significantly worse performance when compared to Tethered condition results (t_{28}=6.50, p<0.0001) as seen in Figure 10.
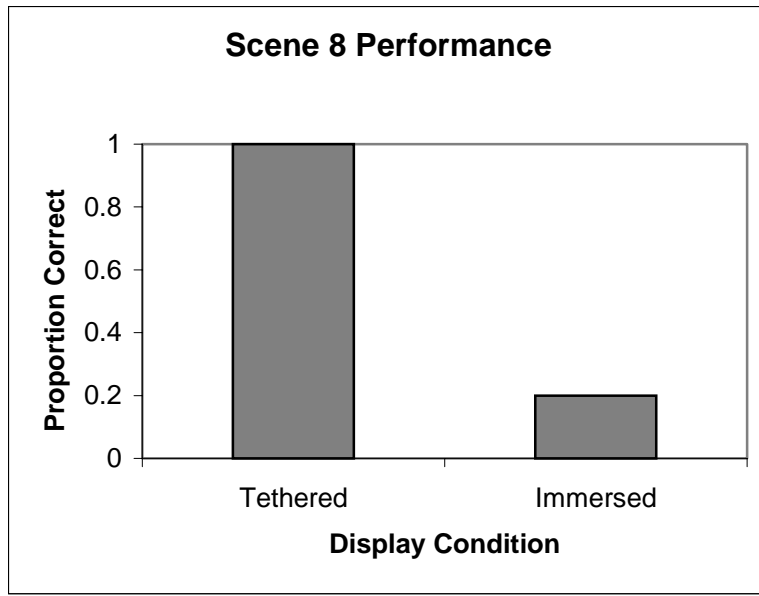
Figure 10. Scene 8 question results by display condition.

In the Tethered condition display, all 5 enemy units (three confirmed, two unconfirmed) are clearly visible (Appendix A, slide 1). In the Immersed condition, 4 of the units (2 confirmed, 2 unconfirmed) are visible, but only two are visible in the initial FFOV of the immersed view (1 confirmed, 1 unconfirmed; refer to slide 2). The 2-D inset map shows 3 confirmed units, two in the initial FFOV (i.e., within the scope of the wedge) and one outside the FFOV (outside the scope of the wedge). Only one of the units in the initial FFOV in the 2-D inset map corresponds to a visible unit in the immersed view; the other FFOV unit in the 2-D inset map is hidden by the terrain in the immersed view and thus is not visible. The second unit in the immersed view's FFOV is *unconfirmed* and therefore is not visible on the inset map. Thus, prior to panning the environment, there are *four* units total that can be distinguished between the 2-D inset map and the immersed view's initial FFOV (three confirmed units in the inset map and one unconfirmed unit in the immersed view). The fifth unit, which is unconfirmed and thus not visible on the 2-D inset map, can only be seen when the subject pans the full range of the environment (refer to slides 3-5 in Appendix A).

All 15 of the Tethered condition subjects chose the correct answer C ("5 companies") for the question, "How many enemy outposts (confirmed AND unconfirmed) are visible?" In the Immersed condition, only 3 subjects (20%) selected the correct answer C ("5 companies"). Eleven subjects (73%) chose answer B ("3 companies"), and one subject (7%) chose answer A ("2 companies"). Observation by the experimenter revealed that the majority (10/11, 91%) of the subjects who chose answer B did not pan the environment at all, and instead relied solely on information provided in the 2-D inset map, even though they had been informed that the inset map did not depict unconfirmed enemy units (which were specified in the question).

Map interpretation analysis (Scene 19). Display condition had an effect on how subjects interpreted the potential threat of enemy units given the terrain. In Scene 19, each display showed 5 new enemy units forming a semi-circle around the intersection at Objective

Illinois (see Methods: Battle Scenario; also refer to Appendix). In the Tethered display, 3 enemy companies are clearly visible, and two more are partially visible behind the mountain range to the north (total of 5 units visible; refer to Appendix A, slide 6). In the Immersed display, all five enemy units are visible in the 2-D inset map, but only 3 companies are clearly visible in the immersed view (2 are completely hidden behind the mountain range; refer to slides 7-10). Subjects were asked the following question: "How many enemy companies are defending and/or can influence the area ahead of you?"

A Chi-square test was performed, which indicated that the distributions of subjects' responses to Scene 19 as shown in Figure 11, differed significantly by display condition ($\chi^2 = 22.58$, p<0.0001). The majority (60%) of Tethered condition subjects selected answer C ("5 companies"), while 33% chose answer B ("4 companies") and only 7% (1 subject) chose answer A ("3 companies"). Immersed condition subjects, on the other hand, overwhelmingly (87%) chose "3 companies", and only 2 subjects (13 %) chose "5 companies". Thus, even though both display conditions showed the same number of new enemy units, subjects were led to different conclusions about how many of these units were potential threats depending on which display condition they were in and how it affected their interpretation of terrain information.
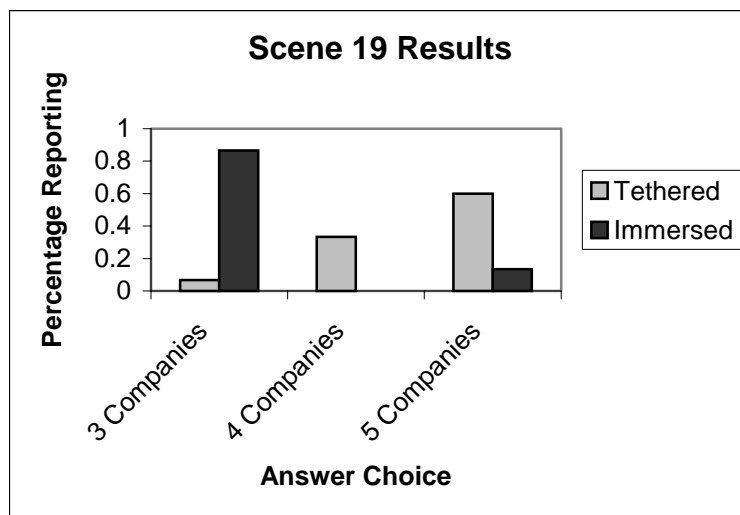

Figure 11. Scene 19 question results by display condition.

Map choice accuracy task. Data from this task were taken from the 32 subjects in the pilot session. There were no significant main effects between the difference in accuracy for display conditions ($t_{62}=1.105$, p<0.27), or map format conditions ($t_{62}=1.105$, p<0.27). Also, there was no significant interaction ([$F(1,62) = 0.12$, p<0.73]; refer to Figure 12) between display type (Tethered vs. Immersed) and map format conditions (3-D perspective map choices, based on the Tethered condition view, vs. 2-D plan-view map choices, based on the Immersed condition display).
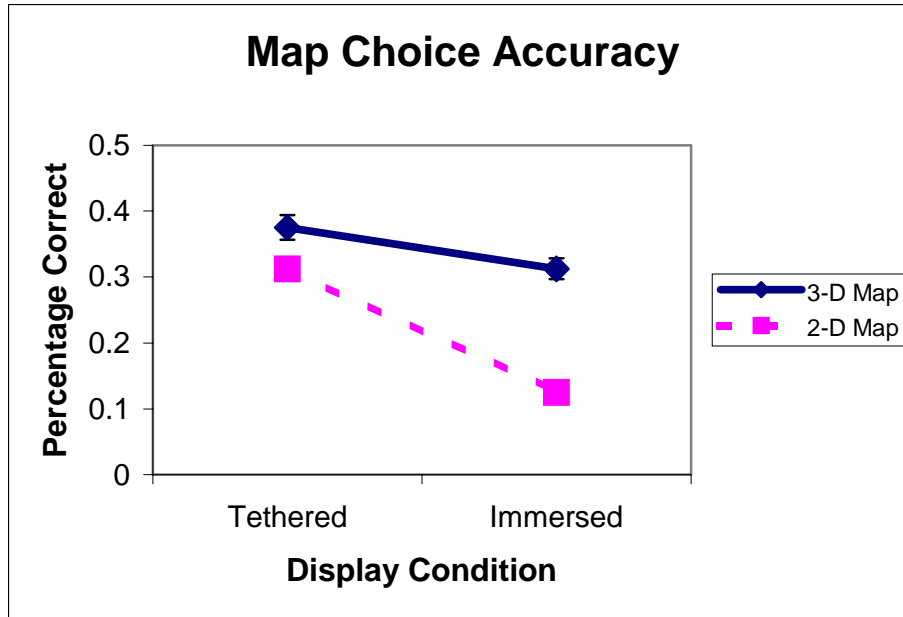
Figure 12. Map choice task results.

Display usefulness ratings. The participants' ratings for each display's usefulness did not differ by display condition ($t_{28} = 0.37$, $p<0.71$) as shown in Figure 13.
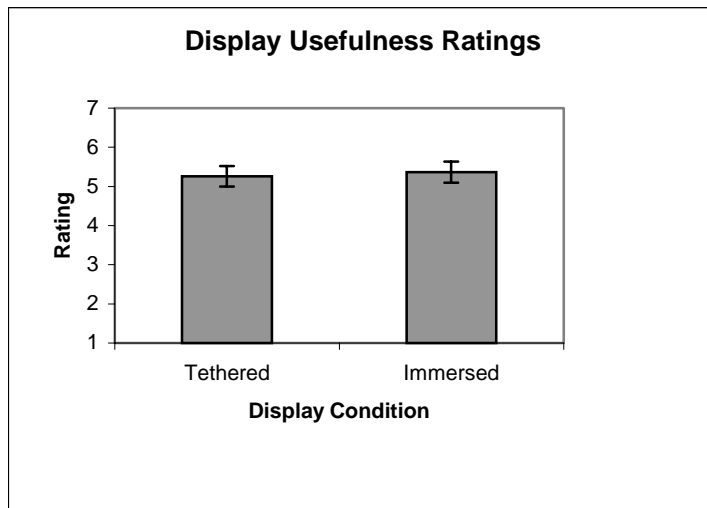

Figure 13. Average display usefulness ratings by display condition, with 95% error bars.

DISCUSSION

The goal of this experiment was to evaluate the effects that different display frames of reference have on decision-making and hazard awareness task components in the context of an on-going ground-based battle scenario. In general, the results of this study support findings from previous research on display frame of reference effects on navigation tasks, as well as provide

evidence of cognitive tunneling in the more immersive display format. The particular performance tradeoffs between display format and type of task are discussed below.

Frame of Reference Effects on Navigational Task Components

      Direction judgments. Direction judgments were equally well supported by both display conditions. The addition of a north-up arrow in the Tethered view and a field-of-view wedge to the 2-D inset map in the Immersed condition was successful in keeping subjects oriented to the cardinal directions.

      Distance judgments. Distance judgments were differentially supported by the two display types. Overall, Immersed condition subjects provided more accurate distance judgments than did the Tethered subjects. Since all of the distance judgment questions referred to objects which were depicted on the 2-D inset map of the Immersed condition, which was the most exocentric FOR, it can be assumed that subjects relied on the 2-D inset map (which had a 10 km grid for scale) rather than the immersed view (which had no scale) to produce their distance estimations. Therefore, this finding replicates findings by Banks, Wickens, and Hah (1998) that 2-D plan-views produced more accurate distance estimations. Additionally, the 1 km bar added to the Tethered view display (similar to that used in Banks et. al., 1998) did not appear to fully compensate for the ambiguity along the line-of-sight, given the subjects' poor performance (refer to Figure 8 in Results). Because the bar was located parallel to the horizon, it did not provide any information on the degree of perspective in the view.

      Global hazard awareness. As shown in Figure 5, the Tethered condition was found to produce better performance on count of enemy units visible than the Immersed condition, supporting the prediction that more exocentric views provide for better global hazard awareness (in this case, awareness of enemy units visible around the subjects' location). Unlike the distance judgment questions, most of the questions in this category included a count of unconfirmed enemy units which were not available on the Immersed condition's 2-D inset map and for which panning of the immersed view was sometimes required. Thus the most exocentric view *which contained the necessary information* in a single view was the Tethered condition's view, which produced higher accuracy on these questions. It is interesting to note that the accuracy scores are not as high in the Tethered condition (60% accuracy) as was expected given that all of the enemy information was available within the view. However, the information varied in quality as some enemy symbols were only partially visible on the sides of the screen or partly hidden behind terrain features such as a mountain range. Analysis of the responses to questions which required inclusion of partially visible units in the count revealed that subjects in the Tethered condition showed poor performance on these questions. This suggests either that subjects are unwilling to include partially visible units in the overall count of enemy units, perhaps because of an inherent ambiguity in the phrasing of the question (i.e., asking for "visible units" may imply that the units must be fully visible on the screen). Alternatively, subjects may have missed seeing the partially visible enemy units if their attention was anchored (tunneled) to more salient features within the display, such as other fully visible enemy units in the center of the screen. This effect is similar to one reported in Yeh, Wickens and Seagull (1998, in press), in which subjects' attention was anchored to a salient (cued) object in the environment which caused them to miss detecting the more important uncued target object.

Tethered condition subjects rated their confidence on these questions as high (refer to Figure 9) despite performance that indicates that they were clearly answering based on incomplete information, lending credence to the suggestion that they were anchoring to an answer based on an initial count of enemy on the screen (but one which appeared among the question's options) because they were not seeking additional information which might contradict it.

While the tethered view subjects showed some deficits to performance, the Immersed condition subjects showed clearly greater deficits to the extent that panning was required. These deficits can be attributed jointly to difficulties in integrating information across the two views – the immersed panel and the 2D inset map (Wickens & Carswell, 1995), and to the inadequacy of panning, with an over-reliance (tunneling) on information in the initial forward views which would cause subjects to forget to search for additional enemy information outside of the initial FFOV). A closer investigation of one scene (Scene 8, described below) in particular revealed that Immersed condition subjects were unable to correctly interpret the information provided in the two displays.

The results from Scene 8 indicate that while subjects in the Immersed condition are able to use the wedge to derive accurate direction estimates (as evidenced by the extremely high performance on direction judgment questions), they do not seem to be able to use the wedge to correctly gather information about the field of view that it provides. Refer to Slides 4-8 in Appendix A. There is a definite anchoring effect demonstrated in this scene, where subjects are mistakenly assigning both enemy symbols in the immersed view's initial FFOV (looking toward the west, Slide 5) to 2 enemy positions in the 2-D inset map which fall within the scope of the wedge. There are two sources of information in the 2-D inset map that should have provided sufficient evidence to the subjects that they were incorrectly mapping the visible symbol to the 2-D inset map position: (1) the contour lines indicating a mountain range between their location and the enemy, and (2) the fact that the enemy in the 2-D inset map was approximately 10 km from their position (further out than the other enemy to the west), while the enemy in the immersed view was approximately 4 km from their position, or closer than the other enemy to the west. Despite these map-based clues, subjects persisted in interpreting these symbols as representing only one enemy position, as evidenced by the fact that 80% of subjects responded that there were only 3 (or 2) enemy units visible. If the subjects had interpreted the dual maps' information correctly, they should have been counting 4 enemy visible between the initial FFOV (which showed two enemy units) and the 2-D inset map (which showed three confirmed positions, one of which was to the south, outside of both the wedge's scope and the initial FFOV), without yet panning the environment. This interpretation would have prompted them to pan the environment, since "4 enemy units" was not an available answer to the question. Panning would have revealed one more unconfirmed enemy unit, thus bringing the total to 5 units. The fact that so few (3 out of 15) subjects selected the correct answer of "5 enemy units" is evidence that the majority of subjects did not pan the environment, choosing instead to anchor to the initial FFOV. Because of this specific diagnosis on Scene 8, we can also infer that the failure to adequately pan was responsible for the for the diminished accuracy of answering other "pan-required" questions, as shown in Figure 5.

Verbal protocol and change detection. Performance on the verbal report task was not high overall; subjects in both conditions missed the majority of status changes from unconfirmed to confirmed enemy units. However, subjects in the Tethered view detected significantly more changes to objects in the environment than did Immersed condition subjects, lending more support to the hypothesis that a more egocentric view disrupts global hazard awareness. In particular, change reporting required the memory of the previous screens to be compared with the visual evidence of the current screen. These memory demands were greater for the Immersed condition view, because the overlapping area of coverage between the two forward views was considerably less than with the tethered condition.

Display Frame of Reference Effects on Decision Making

An investigation of Scene 19's data reveals that subjects interpret terrain information and enemy threat potential differently depending on their display frame of reference. When this scene is presented, the accompanying question box reads, "How many enemy companies are defending and/or can influence the area ahead of you?" The question was posed in this manner, as opposed to the standard phrasing, "How many enemy units are visible?" because the interpretation of "defending" and "influencing" can be affected by the particular terrain features (e.g., the mountain range blocking two of the enemy companies) as well as the specific positions of the enemy in the area. The same information is presented in both scenes, but the form of the presentation differs. Depending on how the subjects evaluated the terrain, the two enemy companies to the north (behind the mountain range) may or may not be considered in a position to move into the area (influence) and threaten the subjects' battalion (defend). A study by Barfield, Hendrix and Bjorneseth (1995) revealed that increased eyepoint elevation led to increasing amounts of error in elevation judgments, which the authors suggest is due to the compression of vertical information as the viewpoint increases in elevation. This effect may account for the difference in response distributions seen in the two display conditions by describing how subjects are judging the terrain differently depending on which display condition they are in. In the Tethered condition both companies are partially visible over the mountain range, which may appear to be less of an obstacle because the high angle (approximately 45 degrees) of the viewpoint reduces the saliency of the elevation information. Subjects in this condition were more likely than those in the Immersed condition to interpret the additional two companies to the north as a potential threat, as shown in Figure 10, because the mountains weren't seen as a protective barrier, and thus include them in the answer. In the Immersed condition, the mountains completely obscure these two companies, which are only visible in the 2-D inset map. The mountain range was a more salient obstacle for the enemy, as viewed in the Immersed condition, when the viewpoint was closer to the ground and allowed for a more accurate perception of altitude. Subjects in the Immersed condition were therefore more likely to exclude these two companies from their answer (refer to Figure 10).

Evidence of Cognitive Tunneling and Overconfidence

The results from the panning category analysis, specifically on the data from Pan-Required questions, provide some evidence that cognitive tunneling is induced in more egocentric displays. As illustrated in the Scene 8 discussion, Immersed condition subjects (who had the panning option) showed worse performance on questions which required the subjects to

pan the environment to obtain all of the information than did Tethered subjects. This interpretation is further supported by the results of questions requiring a count of visible enemy units. Immersed subjects appear to be anchoring to the initial FFOV view and basing their decisions primarily on what information is available in this immersed view, augmented to some degree with the degraded information from the 2-D inset map but were insufficiently sensitive to that which can be gained by panning. This deficiency was evident despite the fact that the response time data in Figure 6 suggested that panning *was* done when it was required. However, the amount of added time (approximately 9 seconds) was that of a continuous revolution, and hence did not suggest any added careful search (i.e., pausing the pan). This finding coupled with the evidence from experimenter observation, the results discussed above, and the results from similar experiments which did find a cognitive tunneling effect with more egocentric frames of reference (e.g., Yeh et al., 1998; Olmos et al., 1997), is highly suggestive of a cognitive tunneling effect in the Immersed display condition.

More evidence of cognitive tunneling comes from the findings that the confidence ratings of the subjects remain extremely high despite variations in their performance, a finding similar to that observed by Banks and Wickens (1997; Banks, Wickens, & Hah, 1998). Performance by subjects in the Immersed condition dropped substantially when panning was required (refer to Figure 5), but the confidence rating was just as high as for questions which did not require panning. Additionally, subjects' confidence ratings were uniformly high regardless of display condition, type of question, or subsequent performance on those questions, indicating that they were confident that their answer selection was based on complete information when clearly some information (outside the FFOV) had not been acquired. This high confidence/low accuracy effect combined with the evidence that Immersed subjects generally did not pan the environment implies that they were cognitively tunneled into the FFOV.

The importance of in appropriately high confidence in the adequacy of information acquisition in a combat environment cannot be overstated since this might lead to a premature commitment to a poorly chosen course of action. The issue of how display features may serve to better calibrate confidence with action is one that calls for further research (Wickens, Pringle, & Merlo, 1999).

Post-Experimental Spatial Reconstruction Task

Results from this task did not support or contradict findings from studies such as Barfield et al. (1995) and McCormick et al. (1998), which both reported that use of more exocentric displays produced an increase in performance on spatial reconstruction tasks. The overall low accuracy on this task, which is not significantly different than chance for any map in any combination of conditions, suggests that the map choices that we provided may have been too difficult (too similar) to adequately assess the subjects' recall of objects in the environment. The differences between the map choices (in both map conditions) were dependent on different groups of units being removed from each map alternative. The correct map, therefore, was the map that contained all of the friendly and enemy units (i.e., the most information). However, the differences may have been too subtle to be detected when, for example, the subject doesn't remember whether they saw one object or two in a certain section of the battlefield, or whether there were any units there at all.

Conclusions

This study was an initial attempt at examining frame of reference effects on spatial judgments, cognitive tunneling, and decision-making information integration biases in the context of a dynamic battle scenario. Our results generally confirmed the hypotheses for display type and task type performance tradeoffs which were derived from previous research in ground-based as well as aviation-based domains. We also found some evidence that supported the hypothesis that more egocentric views would induce cognitive tunneling, to the extent that it selectively affected performance on global judgment and awareness tasks, when such panning was required for an accurate response. The current results also suggest that providing two map views may not necessarily remediate the deficiencies of a single ego-referenced view, if attention is not adequately deployed to integrate information across the two views. Future studies might be able to study the effects of this cognitive tunneling in a more interactive scenario where subjects can make decisions regarding courses of action and implement them, representing even more closely the types of tasks a commander faces on the battlefield. In addition, future studies should offer more extensive training in the strategies necessary to attain all information with each display format. However, even if this is done, it should be borne in mind that training for a displays' inadequacies is not necessarily an adequate justification or compensation for those inadequacies.

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Appendix A

Slide 1: Tethered Condition view of Scene 8

Slide 2: Immersed Condition view of Scene 8, showing initial FFOV (looking west)

Slide 3: Immersed Condition view of Scene 8, showing view to the south

Slide 4: Immersed Condition view of Scene 8, showing view to the east

Slide 5: Immersed Condition view of Scene 8, showing view to the north

Slide 6: Tethered Condition view of Scene 19

Slide 7: Immersed Condition view of Scene 19, showing initial FFOV (looking WNW)

Slide 8: Immersed Condition view of Scene 19, showing view to the SSW

Slide 9: Immersed Condition view of Scene 19, showing view to the ESE

Slide 10: Immersed Condition view of Scene 19, showing view to the NNE

Appendix B: Consent form and Tethered and Immersed instructions

Research Number: _____
(Office Use)

<center>
<u>INFORMED CONSENT</u>
(BEFORE PARTICIPATION)
</center>

I consent to participate in the research entitled

"Human Factors Evaluation of Immersive Virtual Environments Technology for Battlefield Displays"

Conducted by

Christopher D. Wickens, University of Illinois at Urbana-Champaign, and
Lisa C. Thomas, University of Illinois at Urbana-Champaign

My task in the research will be to view a series of computer-generated display panels depicting different evolving aspects of a movement to contact scenario. After each panel, I will answer certain questions regarding the nature of information presented.

Christopher D. Wickens or his representative, Lisa Thomas, explained the procedure and the expected duration of my participation. I am aware that although no physical or psychological harm is anticipated, I may withdraw from participating in this project at any time, without penalty. I was informed that after my participation I will be briefed about the purpose of the research.

I acknowledge that my participation is voluntary and I will be paid $6.00 per hour (min. of 1 hour). I understand the personal information I provide and the data collected will be used for research purposes only. They will be treated confidentially and will not be accessible to anyone outside the research team. A copy of this consent form may be supplied to me. If I have any questions about this research, I may contact Dr. Wickens at 217-244-8617 or Lisa Thomas at 217-244-4461.

Date: _____

Printed Name: _____ (Subject)

Signed: _____ (Subject)

Signed by: _____ (Experimenter/Data Collector)

(Tethered Perspective)

The research for which you have volunteered is a part of the Army
Research Laboratory's Federated Lab project on Advanced and
Interactive Displays, examining concepts for the future digitized
battlefield. The present experiment is designed to examine some
aspects of the DISPLAY VIEWPOINT for presenting battlefield
information.

You are the battalion commander of a mechanized/armored Task Force that is conducting
a Movement to Contact. You are using a new digital 3-D map that the S-3 has just installed in the
back of your command Bradley Fighting Vehicle. The digital 3-D map has a "real time feed"
from satellite imagery, information from Brigade and higher, as well as input that is received
from your own Task Force S-2, Engineer, …etc. Your 3-D map will show you suspected or
templated enemy positions as well as known or confirmed enemy locations. The enemy locations
will be marked with signposts carrying information about the enemy unit. The enemy's real
location is assumed to be at the BASE of the signpost. Roads on the digital map are shown in
white.

During the current operation you will track the battle from this new 3-D map that the S-3
has installed, by viewing a series of 25 successive scenes along the MTC. You will know what
direction your task force is heading by observing the direction that your command tank is facing.
There is an blue arrow on top of your command tank that is always facing due North. This will
help you stay oriented to the cardinal directions. After the first scene, your battalion's position
will be indicated solely by the command tank. Base all distance or direction judgments from the
location of the command tank. To assist you with any distance estimates, a line of 1 KM length is
shown extending leftward from your command tank's location.

PROCEDURE:
There are two tasks in this experiment: the first is to verbally announce any new enemy
units, or changes to existing units, and to give as much information about them as possible.
Whenever you see any new enemy symbols on the screen, please state size, type, distance, and
direction. For example: "Unconfirmed enemy armor platoon located 7 kilometers due west of my
battalion's position" or "Confirmed enemy infantry company located about 5 kilometers
northeast of my position." Changes to an enemy symbol, such as from templated (i.e., a dashed
line symbol) to confirmed (i.e., a solid line symbol), should be announced. Similarly, if an enemy
company is reduced to one or two platoons in the course of an attack, that change should also be
announced aloud.

The second task is to answer the questions in the boxes to the right of the map display. As
you track the operation, 1 to 3 questions per scene will be presented on the screen asking about
the terrain, your unit, the enemy, direct line of fire, etc. The range for direct line of fire is
assumed to be 2.5 km for all enemy units. Please answer each question to the best of your ability,

by dragging the cursor over the correct answer and clicking with the left mouse button, and then rate your confidence for the answer that you selected (ratings will be "Highly confident," "Moderately confident," or "Not at all confident"). The menu driven question format will be self explanatory. Remember, **the oral announcement of enemy graphics symbols is the first priority**, and then answer the questions posed by the computer. You will be given a maximum of 3 minutes to respond to all questions in each scenario. If the experimenter says your time is up, please click the "Timed Out" response for any/all remaining questions. We encourage you to offer your responses in a timely fashion, but be aware that the number of questions varies per scene, so use caution when proceeding to the next question and be sure to examine the map for changes in position, indicating a new scene. As in any command decision-making, it may be important for you to remember information about previous scenes as you view successive scenes.

SCENARIO:

Your Task Force is conducting a Movement to Contact along axis Gold. Your final objective is OBJ Illinois located in the far West of your sketch. You expect to find several combat outposts along your route, but you don't expect to hit the enemy's main defensive belt until you are closer to OBJ Illinois.

<u>Situation Brief</u>

(Immersed Perspective)

The research for which you have volunteered is a part of the Army Research Laboratory's Federated Lab project on Advanced and Interactive Displays, examining concepts for the future digitized battlefield. The present experiment is designed to examine some aspects of the DISPLAY VIEWPOINT for presenting battlefield information.

You are the battalion commander of a mechanized/armored Task Force that is conducting a Movement to Contact. You are using a new digital 3-D map that the S-3 has just installed in the back of your command Bradley Fighting Vehicle. The digital 3-D map has a "real time feed" from satellite imagery, information from Brigade and higher, as well as input that is received from your own Task Force S-2, Engineer, …etc. Your 3-D map will show you suspected or templated enemy positions as well as known or confirmed enemy locations.

During the current operation you will track the battle from this new 3-D digital map that the S-3 has installed, by viewing a series of 25 successive scenes along the MTC. There are two parts to this map display, an immersed view map which occupies most of the display, and a small contour inset map located at the top center of the display. The immersed view shows you the view from just above the commander's vehicle on the ground. The immersed view will show you suspected (templated) enemy positions as well as known or confirmed enemy locations. All enemy locations will be marked with signposts carrying information about the enemy unit. The enemy's real location is assumed to be at the BASE of the signpost. You are able to interact with the immersed view by "panning" left and right. Place the cursor over the immersed view display and press either the left mouse button (to turn the view towards the left), or the right mouse button (to turn towards the right).

Your position on the north-up inset map will be represented by a yellow circle, and your field of view is represented by a light blue "wedge." This wedge highlights the area of the map which is shown in the 3-D immersed view below the inset map. The angle of the wedge shows the extent to the left and right that you can see; anything included within the angle of the wedge should be visible in the forward field of view unless obscured by the landscape, and anything falling outside the extent of the wedge is not visible from that position. As you pan left or right in the immersed view, the wedge will rotate in the corresponding direction on the inset map, highlighting the area of the inset map that you are now seeing in the immersed view. The initial position of the wedge also shows you what direction your task force is heading: the wedge opens up in the direction your task force is facing, and your exact heading can be determined by bisecting the angle of the wedge. This inset map will only have CONFIRMED ENEMY locations, marked with small red diamonds. NO unconfirmed enemy or friendly squads will appear on the inset map. Each grid on this inset map is equivalent to 10 km on a side – this is emphasized with a black bar in the center bottom of the inset map, which indicates 10 km. Roads on the 3-D immersed-view map are shown in white. Roads on the inset map are in black.

PROCEDURE:

There are two tasks in this experiment: the first is to verbally announce any new enemy units, or changes to existing units, and to give as much information about them as possible. Whenever you see any new enemy symbols on the screen, please state size, type, distance, and direction. For example: "Unconfirmed enemy armor platoon located 7 kilometers due west of my battalion's position" or "Confirmed enemy infantry company located about 5 kilometers northeast of my position." Changes to an enemy symbol, such as from templated (i.e., a dashed line symbol) to confirmed (i.e., a solid line symbol), should be announced. Similarly, if an enemy company is reduced to one or two platoons in the course of an attack, that change should also be announced aloud.

The second task is to answer the questions in the boxes to the right of the map display. As you track the operation, 1 to 3 questions per scene will be presented on the screen asking about the terrain, your unit, the enemy, direct line of fire, etc. The range for direct line of fire is assumed to be 2.5 km for all enemy units. Please answer each question to the best of your ability, by dragging the cursor over the correct answer and clicking with the left mouse button, and then rate your confidence for the answer that you selected (ratings will be "Highly confident," "Moderately confident," or "Not at all confident"). The menu driven question format will be self explanatory. Remember, **the oral announcement of enemy graphics symbols is the first priority**, and then answer the questions posed by the computer. You will be given a maximum of 3 minutes to respond to all questions in each scenario. If the experimenter says your time is up, please click the "Timed Out" response for any/all remaining questions. We encourage you to offer your responses in a timely fashion, but be aware that the number of questions varies per scene, so use caution when proceeding to the next question and be sure to examine the map for changes in position, indicating a new scene. As in any command decision-making, it may be important for you to remember information about previous scenes as you view successive scenes.

SCENARIO:

Your Task Force is conducting a Movement to Contact along axis Gold. Your final objective is OBJ Illinois located in the far West of your sketch. You expect to find several combat outposts along your route, but you don't expect to hit the enemy's main defensive belt until you are closer to OBJ Illinois.

APPENDIX C: Questionnaire and Final Consent Form

Debrief

Participant's Name:_____   Rank:_____

      I would like to thank you for your time in participating in this experiment. Your insight is of particular interest to me. Would you please take the time to answer a few questions? Please feel free to continue on the back for any of the questions that you need more space to reply.

1. How many years have you been serving on active duty? _____ years

2. What branch of the Army are you in (Infantry, Armor, etc.)? _____

3. Were the instructions clear to you as far as what you were supposed to do? Yes or No If no, please explain. _____
_____
_____

4. On a scale of 1 to 7, how well do you feel that this display would support your awareness of the evolving battlefield situation? (Circle the number)

	moderately	extremely
useless	helpful	helpful

   1   2   3   4   5   6   7

5. What was particularly helpful or what did you like about the 3-D perspective?
_____
_____
_____

6. What was a particular hindrance or what did you not like about the 3-D perspective?
_____
_____
_____

7. Is there anything that you would add to the map or displays, or other changes you would make, that you feel would improve the displays?
_____
_____
_____

Research Number:
(Office Use)

<center>INFORMED CONSENT</center>
<center>**(AFTER PARTICIPATION)**</center>

I have completed participation in the above research project. My participation lasted _____ hour(s) and _____ minutes. The purpose of the research was to compare two alternative formats for presenting 3-D or perspective battlefield and terrain information. You were assigned to a group that received either an "outside-in" perspective view from above and behind your unit, or an "immersed" or virtual environment view, in which your viewpoint was positioned at the location of your unit. Our previous research, conducted here last year, revealed that each viewpoint had its benefits and costs for simple geographical judgments. In this experiment we are interested in differences related to the display support for more complex dynamic characteristics of battlefield evolution. If you would like a copy of the report describing the results of this experiment, please indicate below, and we will provide you with a copy when it is complete.

I was fully debriefed regarding the purpose of this project. I was also given the opportunity to obtain further information about the research. All my questions have been answered to my satisfaction.

Date: _____

Printed Name: _____

Signed: _____ (Subject)

Signed: _____ (Experimenter)

I would like a copy of this report. Mailing address at USMA: _____

_____

_____